The Future of EUV sources:
a FIRE perspective

C Fanara

EPPRA sas

2010 International Workshop on Extreme Ultraviolet Sources
University College Dublin ▪ Dublin, Ireland - November 13-15 2010

OUTLOOK

1. EPPRA: who we are
2. EU MARIE CURIE ACTION: IAPP
3. PROJECT AIMS
4. MILESTONES

EPPRA: who we are



SME founded in 1996 by Dr Peter Choi and Dr Carmen Dumitrescu
Mission: transfer and transform advanced pulsed power and plasma technology from lab to commercial and industrial applications. EPPRA participates / coordinates, a number of projects under different EU research and technology development programmes and works in

- Compact pulsed power generators
- EUV radiation sources
- Ultra low dose X-ray radiography
- Neutron interrogation processes
- High energy density ion beams surface treatment for engineering applications

EPPRA: who we are

Some past and current activities.
-EUREKA ! 2307 FUSECOAT, “Innovative System for High Rate Low Temperature Ultra-Hard Coatings”

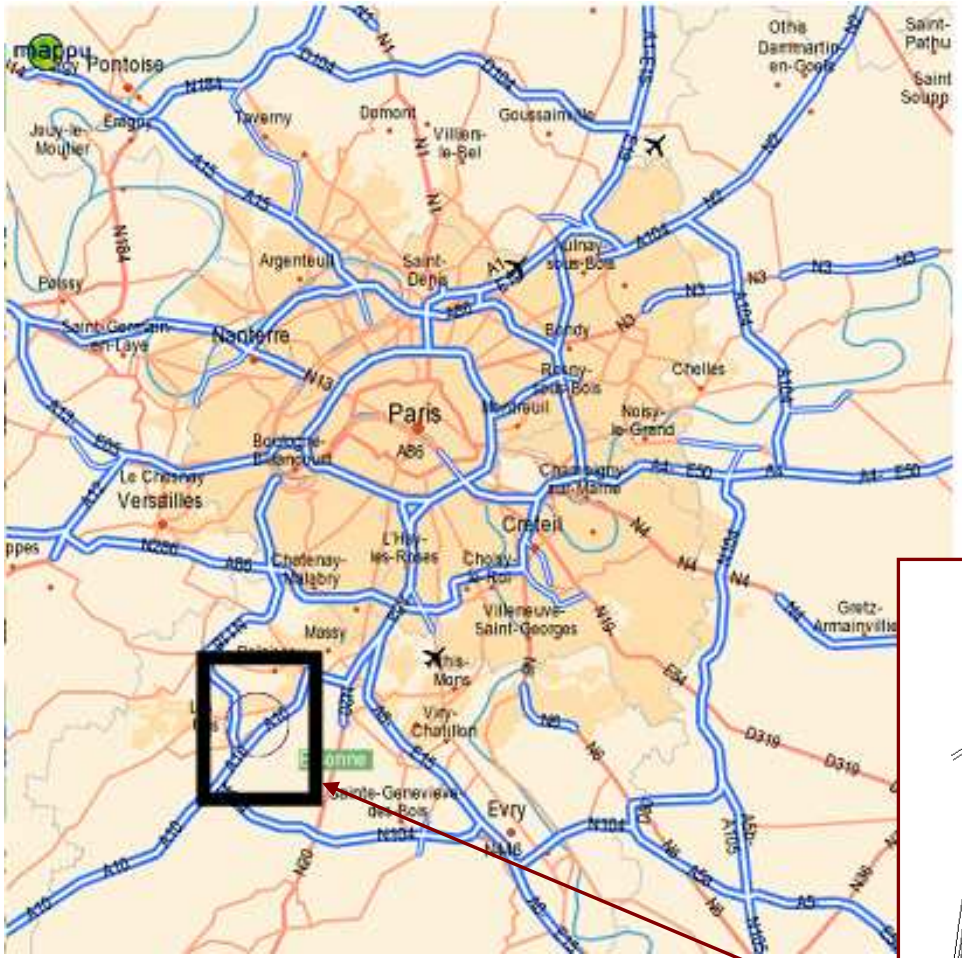
-OSEO PROGRAMME (National, 2007-2008): HEDI-Source; High Energy Density Ion Source.

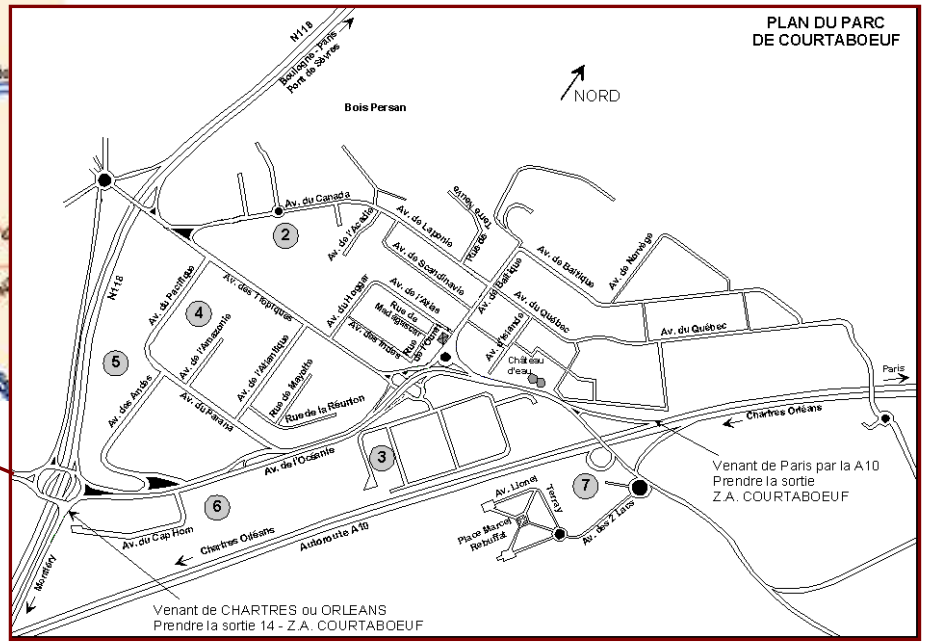
Current projects:
-FP7-PEOPLE-IAPP-2008 project, Marie Curie Actions (FIRE project, Fluid, Ions and Radiation Ensemble in Integrated Plasma Modeling)

- MNT ERA-NET, FIMED, Functionalized Implants for Medicine

A number of EU projects in the security sector;
French national R&D contracts.

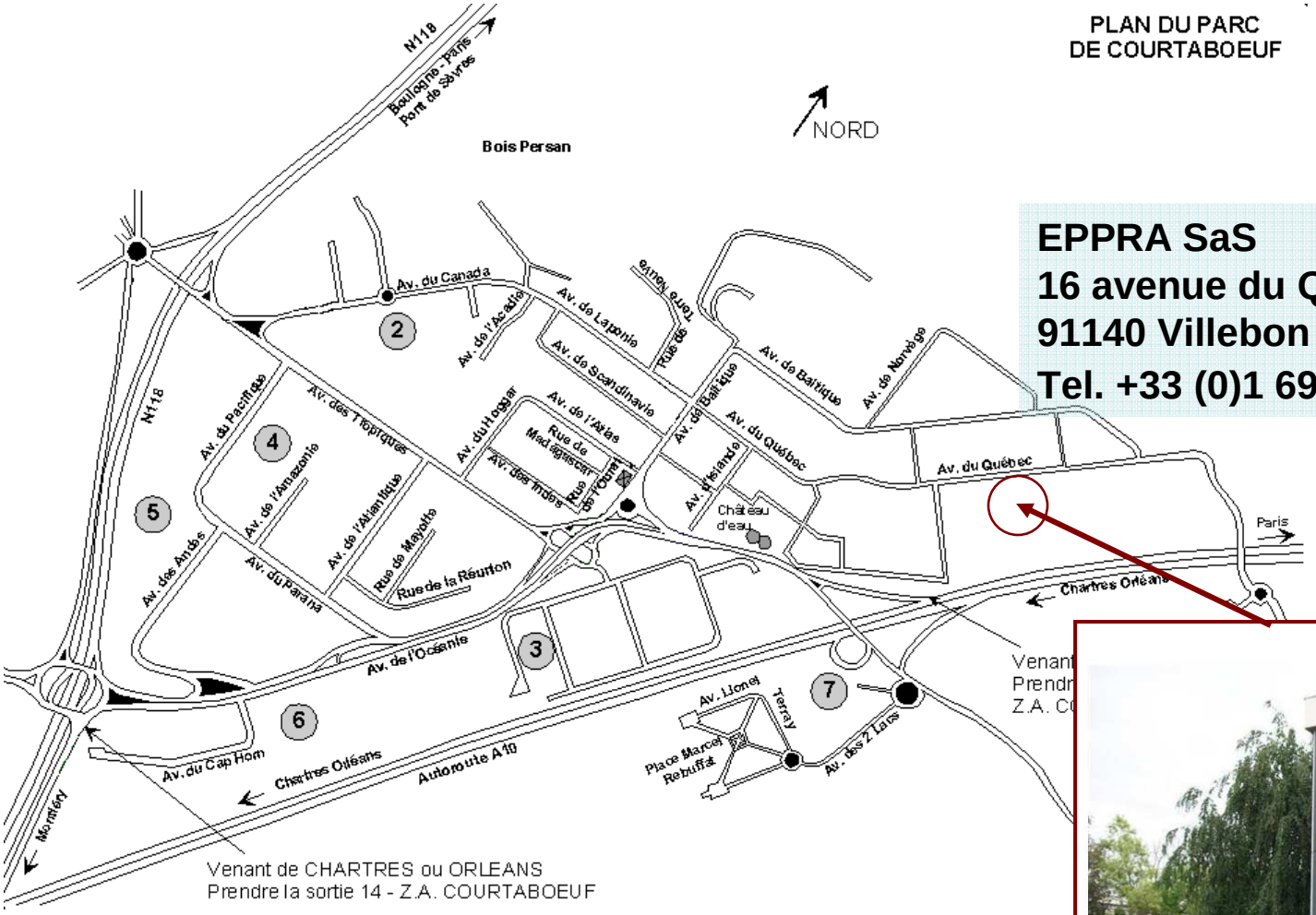
EPPRA: where we are (I)





ZA Courtaboeuf

EPPRA: where we are (II)



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Industry-academia pathways and partnerships (IAPP)

..stimulate inter-sector mobility, increase knowledge sharing through joint research partnerships in longer term co-operation programmes between organizations from academia and industry, in particular SMEs, including traditional manufacturing industries.

Funding available for:

Exchange of know-how and experience: inter-sector two-way secondments of research staff with in-built return mechanisms, Staff to attend events in a trans-national setting.

Recruitment of experienced researchers from outside the partnership for transfer of knowledge and/or training of researchers.

Networking activities, organization of workshops and conferences to facilitate sharing of knowledge and culture between the participants in wider setting, the participants' research staff and external researchers.

FIRE

SEVENTH FRAMEWORK PROGRAMME
THE PEOPLE PROGRAMME

IAPP - Industry-Academia Partnerships and Pathways

Grant agreement no.: PIAP-GA-2009-230726
Project full title: Fluid, Ions and Radiation Ensemble in Integrated Plasma Modeling
Project acronym: FIRE
Duration of the project: 48 months

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FIRE consortium

EPPRA SaS – Paris area, France (coordinator)

Atomic, molecular and plasma physics (Spectroscopy) group of the School of Physics at University College Dublin

KIAM - Keldysh Institute of Applied Mathematics, Moscow, Russia (Russian Academy of Sciences)

FIRE

Fluid, Ions and Radiation Ensemble in Integrated Plasma Modelling

R-MHD Modeling of plasma-based light sources and nanoparticle generation created by intense lasers and high-current pulsed discharges

The project involves radiative plasma dynamics and the physical mechanisms leading to condensation and nucleation.

Multidisciplinary:
atomic physics, plasma physics, spectroscopy, nanotechnology, pulsed power technology, numerical methods, computer simulation, data mining, parallel computing architecture...
(and education, innovation, and IPR management).

Next Generation Modelling Tools
- FP7 IAPP project FIRE

• Theoretical models and robust modeling tools are developed under international collaboration in the frame of European FP7 IAPP project FIRE

• The FIRE project aims to substantially redevelop the Z* code to include improved atomic physics models and full 3-D simulation of

- ✓ plasma dynamics
- ✓ spectral radiation transport
- ✓ non-equilibrium atomic kinetics with fast electrons
- ✓ transport of fast ions/electrons
- ✓ condensation, nucleation and transport of nanosize particles.

• Modelling can be the key factor to scientific and technological solutions in EUVL source optimization with fast particles and debris to solve current EUVL source problems as well as extending their application to 22nm and beyond.

• The research and transfer of knowledge is focused on two major modeling applications;

- ✓ EUV source optimization for lithography and
- ✓ nanoparticle production for nanotechnology.

• Theoretical modelling will be benchmarked by LPP and DPP experiments

Courtesy S.Zakharov

FIRE OBJECTIVES (I)

1) Develop non-equilibrium plasma model with full system of MHD equations, ion level-population kinetic equations (including non-equilibrium electron and radiation Processes).
2) Electron wave functions, energy levels, oscillator strengths, rate coefficients of elementary processes and ion distribution using Hartree-Fock-Slater self-consistent Cowan code (implemented at UCD) and THERMOS codes (KIAM).
3) Tables for detailed and unresolved transition array (UTA) emission /absorption spectra of different substances
4) Thermodynamics equation of state in wide range of temperatures and densities for different substances in average atom (ion) statistical model
5) Incorporate the statistical UTA methodology (UCD) into Z* code (EPPRA) including re-absorption of radiation due to cold peripheral plasma
6) Develop computational algorithms for using non-equilibrium constants in kinetics and gas-dynamic calculations, construct and analyze suitable interpolation to obtain the absorption coefficients and emissivity of non-equilibrium plasmas for different substances \ substance mixtures.
7) Develop improved adaptive grids in the Euler-Lagrange difference scheme to address problems in Complex geometries, including effect of targets, electrodes and insulators with possible sublimation (condensation) of solid materials and mixing.
8) multi-dimensional data analysis of conversion efficiency in LPP EUV sources, using different laser parameters, target geometries, for different elemental concentrations and angles.
In particular: effect of pulse shaping and multiple pulses illumination.
Simulation results will be compared with detailed experiments at UCD.

→ → →

FIRE OBJECTIVES (II)

9) Study debris production with selected LPP source parameters; assess optimum radiation generation conditions while minimizing debris. Comparison with similar effort to study optimized radiation production in DPPs.

10) Adapt existing 3-D particle-in cell (PIC) numerical algorithm (KIAM) for the calculating subprogram development used:

A- as parallel processor to the main MHD processing to calculate electron, ion distribution at plasma edge, acceleration by applied external electric field or self-consistent ambipolar potential into ambient gas with possible collisions, recombination and charge exchange with ambient gas,

B- as a parallel processor of transport of nanoparticles after condensation and nucleation of the plasmas during interaction with the ambient gas.

11) Develop 3-D spectral radiation transport model with UTA spectral tables for main MHD processor to calculate plasma dynamics, and as a post-processor to calculate spectral composition of plasma emission for radiation source as well as for spectral diagnostics.

12) Develop the 3-D modeling for parallel computation on a multiprocessor Blade array computer. This includes PIC calculating subprogram, spectral radiation transport model and the RMHD code with existing (EPPRA) software tools for data input/output.

13) Study the plasma-gas condition for production of size controlled nanoparticles through rapid quenching of an energetic plasma of a discharge expanding into a neutral gas

14) Develop a user-friendly interface and create a user's manual with sample runs and a database of test cases. Publish a number of journal articles related to optimizing in-band EUVL radiation.

FIRE: deliverables and milestones

Milestone no.	Milestone name	WPs no's.	Lead beneficiary short name	Delivery date	*Comments*
1	UTA	1	EPPRA	month 12	Plasma modelling using Z* with UTA in EUV range
2	**Fast**	3	KIAM	month 18	Modelling of acceleration of fast particles from plasma
3	**Data**	4	UCD	month 22	Database on laser/target condition for optimum EUV source
4	**MHD**	2	KIAM	month 30	Demonstrate adaptive grids in MHD plasma modelling
5	**Parallel**	3	KIAM	month 30	Parallel computing calculations of plasma spectral emission
6	**LPP**	1	UCD	month 36	Demonstrate re-absorption effects in LPP EUV source
7	**3D**	2	EPPRA	month 44	Modelling of 3-D dynamics and spectral emission of plasma
8	Nano 1	3	EPPRA	month 44	Modelling of formation of nanoparticles from plasma expanding into gas medium
9	Nano 2	4	EPPRA	month 44	Demonstration of size controlled nanoparticles production from plasma

Workshop 1: Physical modeling of Industrial Plasma Radiation Sources Theory and Benchmarking (Dublin, 2011).

FIRE: Work Packages

Work package No	Work package title	Lead Beneficiary short name	Start month	End month
WP1	Ionization dynamics and spectral radiation transfer	UCD	1	36
WP2	2-D RMHD upgrade and 3–D RMHD code development	EPPRA	1	48
WP3	3-D PIC calculating subroutine implementation and parallel computing	KIAM	1	48
WP4	Modelling and experiment of high energy density plasmas	EPPRA	1	48

Relevant to FIRE in this workshop:

Clinton Auditorium, 5:30 -7:00 PM,
November 14, 2010

Session 5: EUV Sources for EUV Metrology - 1
Multiplexed EUV Sources based on a Compact Module with High Irradiance and Low Etendue for Actinic Inspections and Metrology Applications
Sergey V. Zakharov, NanoUV

Session 7: Poster Session -
Topic: EUV Sources for Metrology
...
12. Influence of High Energy Electrons on EUV and Soft X-ray Emission Spectra of Nonequilibrium Plasma (P32)
Vasily S. Zakharov, EPPRA
13. High Intensity EUV and Soft X-ray Plasma Sources Modelling (P33)
Sergey V. Zakharov, NanoUV

High intensity EUV and soft X-ray plasma sources modelling

Sergey V. Zakharov[+], Vasily S. Zakharov[+],Peter Choi,
Alex Yu. Krukovskiy, Vladimir G. Novikov, Anna D. Solomyannaya

NANO-UV sas

EPPRA sas

KIAM RAS

[+] also with RRC Kurchatov Institute

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Thank you!